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C O N T E N T S

TECHNOLOGIES

Simulation of toolpaths and program verification of a CNC lathe machine tool

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Abstract: *This paper presents the simulation and verification of programs created for the CNC Hitachi Seiki Seicos LIII lathe machine tool. The main purpose of program simulation and verification is to ensure the quality and accuracy of the cutting process, which can significantly improve production efficiency. In addition to defining the toolpath, simulation can perform linear and circular interpolation according to specific programs based on G - codes. Therefore, all the motions of the moving parts of the real lathe machine tool can be clearly visualized. The use of simulation is a good solution not only to precise the toolpath, but also verify the program and detect any possible collision between cutting tools and mobile components, before loading the program into the lathe machine tool and starting cutting processes.*

Keywords*: MANUFACTURING, MACHINING, PROGRAMMING, CODES, SOFTWARE*

1. Introduction

Constant monitoring and control over the dimensions, dimensional tolerances, and surface finish of the designed parts during the manufacturing process provides increased process efficiency and product durability.

Therefore, Computer Numerical Controlled (CNC) machine tools have been widely implemented in the manufacturing industry in the last few years for the reason that their reliability is greater than that of conventional manufacturing machine tools. In order to machine the part in a drawing by using CNC machine tools, it is necessary to generate a series of instructions for activating those CNC machine tools. This task is called CNC programming [1].

CNC programming is a term that refers to the methods for generating the instructions that drive the CNC machine tool [2]. A series of instructions to be performed by the CNC machine tool compose a program of instructions. It consists of G – codes, also known as geometric codes, that control the motion of the machine tool. The standard format for a G – code command begins with "G" and is followed by a two – digit number. These common G – code instructions provide the geometric position of the moving parts of the machine tool, which is generally determined by a coordinate system, as an instrument for identifying the location of the moving parts, moving them in a particular direction, and indicating their precise position in 3D space. This programming language also includes M – codes that control the CNC machine tool or its functions (such as spindle rotation speed, cutting tool feed, cutting tool change, coolant, etc.). M – codes are also written in alphanumeric format, beginning with "M" and two digits following.

G – code, in the act of being a programming language, leads to particular programs of instructions generated by Computer – Aided Manufacturing (CAM) systems that use Computer – Aided Design (CAD) information. These innovative manufacturing systems are used to both design and manufacture products, and they significantly improve the design and productivity of manufacturing processes.

CAD refers to the implementation of computer technology for design and design documentation. On the other side, CAM software programs are used for generating tool paths and verifying program correctness.

The purpose of CAM software programs is to design products and arrange manufacturing processes, particularly CNC machining. Extremely complex parts in large quantities, requiring complex machining processes, are produced on CNC machine tools. Most frequently, final parts and prototypes are machined using CAD/CAM software programs. As a consequence, before being applied to an actual CNC machine tool, these complex manufacturing processes need to be thoroughly verified. For that reason, one of the most well-known, practical, and helpful CAM software programs is the Computer Numeric Control (CNC) Simulator.

The CNC Simulator is an application designed to predict the behavior, performance, and outcome of certain manufacturing processes based on simulation - driven design that has been defined by Sellgren [10] as: "a design process where decisions related to the behaviour and the performance of the design in all major phases of the process are significantly supported by computer – based product modelling and simulation".

Simulation in manufacturing refers to a broad collection of computer based applications to imitate the behavior of manufacturing systems [2]. Numerous simulation software programs have been developed to graphically verify the program of instructions prior to running the part on the machine tool with an actual workpiece. Because of the complexity of generating the program of instruction, simulation software was developed to identify programming errors prior to actual part production. Additionally, it is much easier to edit the program of instruction at this stage of development [3].

The information input to the program regarding the toolpath, tool, material, and parameters specific to each are linked to the geometry. This means that if any of the parameters for the parts mentioned above are changed, the other related data can be regenerated to take these changes into account without recreating the entire operation [4].

2. Research

This research illustrates a simulation of part of the clutch hub manufacturing process. It refers to a machining chip removal process that can be performed on a CNC Hitachi Seiki Seicos LIII lathe machine tool.

Machining is one of the most important manufacturing processes. Machining is a manufacturing process in which a sharp cutting tool is used to cut away material to leave the desired part shape. The predominant cutting action in machining involves shear deformation of the work material to form a chip; as the chip is removed, a new surface is exposed. Machining is most frequently applied to shape metals [8].

Machining with chip removal includes methods in which the design of workpieces is achieved by removing excess of materials [9].

Machining is not just one process; it is a group of processes. There are many kinds of machining operations, each of which is capable of generating a certain part geometry and surface texture The common feature is the use of a cutting tool to form a chip that is removed from the workpart. [8].

In this research, the required machining operations to machine the clutch hub on the mentioned CNC lathe machine tool are discussed. These are: turning, boring, drilling, facing, and chamfering.

In the turning process, the cutting tool is set at a certain depth of cut (mm) and travels to the left with a certain velocity as the workpiece rotates. The feed, or feed rate, is the distance the tool travels horizontally per unit revolution of the workpiece (mm/rev). This movement of the tool produces a chip, which moves up the face of the tool [12].

Turning, boring and drilling generate cylindrical or more complex surfaces of rotation. Facing, also carried out on a lathe, generates a flat surface, normal to the axis of rotation, by feeding the tool from the surface towards the center or outward from the center. [11]

In order to analyze the cutting operations, accurate 2D drawings have been created using a CAD system, i.e., AutoCAD software, for the starting and final workpieces. The starting workpiece is a forged clutch hub (Fig. 1b), and the final part is the machined clutch hub (Fig. 1a).

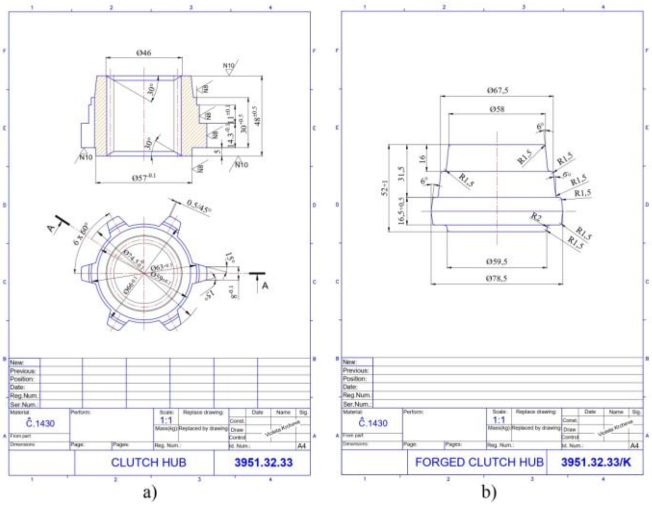


***Fig. 1** (a) Clutch hub, (b) Forged clutch hub*

To precisely define the metal cutting processes performed on this CNC lathe, these drawings are converted into simple 2D models. In that way, the kind of metal cutting operation and final geometry of the part in every phase of the manufacturing process can be clearly explained. Depending on which side of the clutch hub is machined, two phases are determined.

The first phase refers to the shorter side of the forged clutch hub and is defined by four passes.

The first pass (Fig. 2a) is drilling, and the chosen cutting tool is a straight - flute drill DS20 - D3400DM40 – 04 (Fig. 2b) that uses indexable inserts, produced by SANDVIK Coromant.

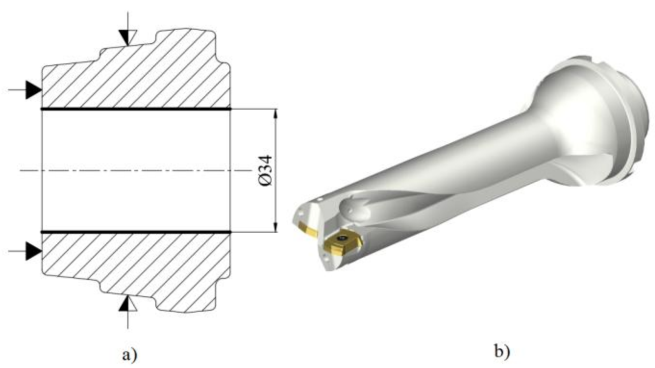


***Fig. 2** (a) First pass, (b) Straight - flute drill that uses indexable inserts*

The second pass (Fig. 3a) is defined by two cutting operations: turning and facing. The chosen cutting tool is a combination of the PCLNR 2525M 12 shank tool (Fig. 3b) and the CNMG 12 04 08-PM 4325 indexable insert (Fig. 3c), both produced by SANDVIK Coromant.

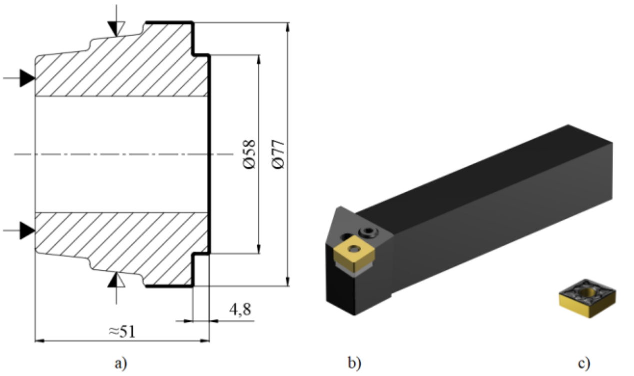


***Fig. 3** (a) Second pass, (b) Shank tool, and (c) Indexable insert*

The third pass (Fig. 4a) is defined by two cutting operations: turning and facing. The chosen cutting tool is a combination of the DDHNL 2525M 15 shank tool (Fig. 4c) and the DNMG 15 06 08-KF 3225 indexable insert (Fig. 4b), both produced by SANDVIK Coromant.

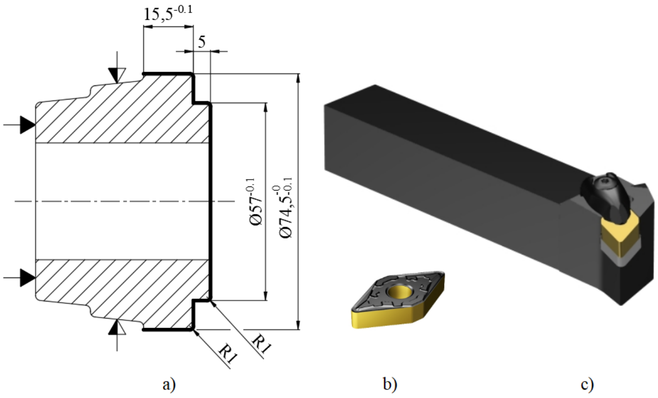


***Fig. 4** (a) Third pass, (b) Indexable insert, and (c) Shank tool*

And the fourth pass (Fig. 5a) is defined just by one cutting operation: chamfering. The chosen cutting tool is a combination of the S25T-PTFNR16 16-W shank tool (Fig. 5b) and the TNMX 16 04 08-WF 1515 indexable insert (Fig. 5c), both produced by SANDVIK Coromant.

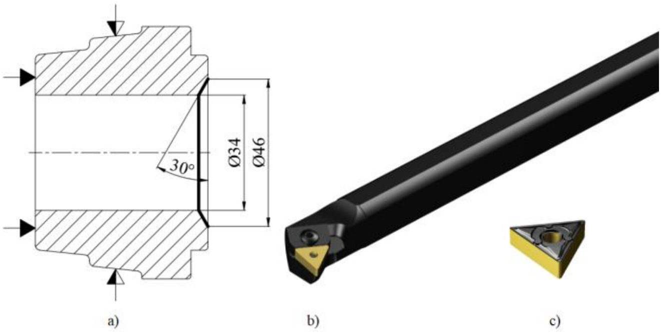


***Fig. 5** (a) Fourth pass, (b) Shank tool, and (c) Indexable insert*

The second phase refers to the longer side of the forged clutch hub and is defined by three passes.

The first pass (Fig. 6a) is defined by two cutting operations: turning and facing, and the chosen cutting tool is the same as in the second pass in the previous phase (Fig. 3b, Fig. 3c).

The second pass (Fig. 6b) is defined by two cutting operations: turning and facing, and the chosen cutting tool is the same as in the third pass in the previous phase (Fig. 4b, Fig. 4c).

And the third pass (Fig. 6c) is defined by two cutting operations: chamfering and boring, and the chosen cutting tool is the same as in the fourth pass in the previous phase (Fig. 5b, Fig. 5c).

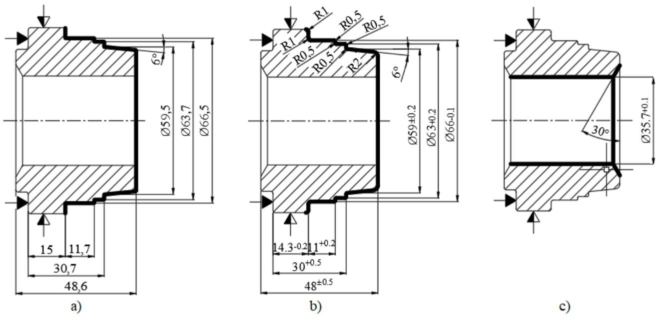


Fig. 6 *(a) First pass, (b) Second pass, and (c) Third pass*

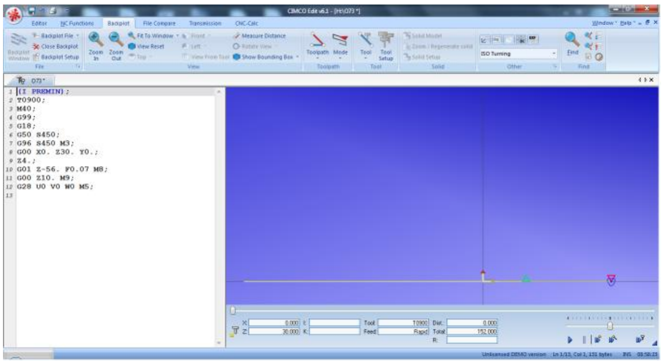
Additionally, for each cutting operation, a program of instructions is created. In that way, two programs of instructions are created, and each one is simulated and verified by the CIMCO Edit v6.1 software program.

.3. *Results and discussion*

Considering the created programs of instructions, in the CIMCO Edit v6.1 software program, the toolpath of the chosen cutting tool is visualized for each of the passes, for every cutting operation. Each block of the program of instructions is provided in a clear manner in accordance with a certain pass (or the complete phase).

The following pictures present a simulation of the toolpath corresponding to the program of instructions created for the mentioned passes and phases, testing and verifying it in the process of design and development.

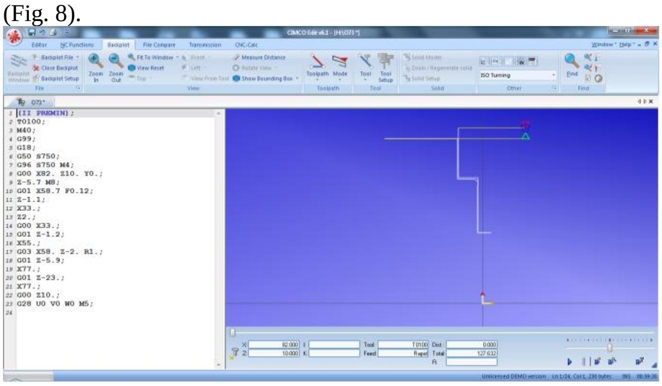
A linear interpolation movement on the cutting tool using the Z-axis as the direction of movement completes the first pass in the first phase (Fig. 7).



```
(I PREMIN);
T0900;
M40;
G99;
G18;
G50 S450;
G96 S450 M3;
G00 X0. Z30. Y0.;
Z4.;
G01 Z-56. F0.07 M8;
G00 Z10. M9;
G28 U0 V0 W0 M5;
```

Fig. 7 *Simulation of the first pass*

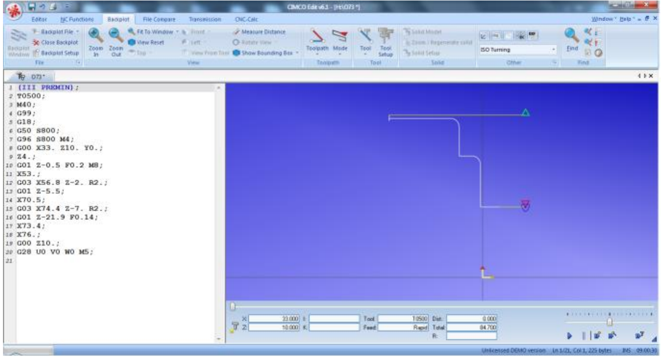
The cutting tool is moved linearly and circularly interpolatively along the X and Z axes to finish the second pass in the first phase (Fig. 8).



```
(II PREMIN);
T0100;
M40;
G99;
G18;
G50 S750;
G96 S750 M4;
G00 X82. Z10. Y0.;
Z-5.7 M8;
G01 X58.7 F0.12;
Z-1.1;
X33.;
Z2.;
G00 X33.;
G01 Z-1.2;
X55.;
G03 X58. Z-2. R1.;
G01 Z-5.9;
X77.;
G01 Z-23.;
X77.;
G00 Z10.;
G28 U0 V0 W0 M5;
```

Fig. 8 *Simulation of the second pass*

Linear and circular interpolation motions on the cutting tool oriented on the X and Z axes complete the third pass in the first phase (Fig. 9).



```
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M40;
G99;
G18;
G50 S800;
G96 S800 M4;
G00 X33. Z10. Y0.;
Z4.;
G01 Z-0.5 F0.2 M8;
X53.;
G03 X56.8 Z-2. R2.;
G01 Z-5.5;
X70.5;
G03 X74.4 Z-7. R2.;
G01 Z-21.9 F0.14;
X73.4;
X76.;
G00 Z10.;
G28 U0 V0 W0 M5;
```
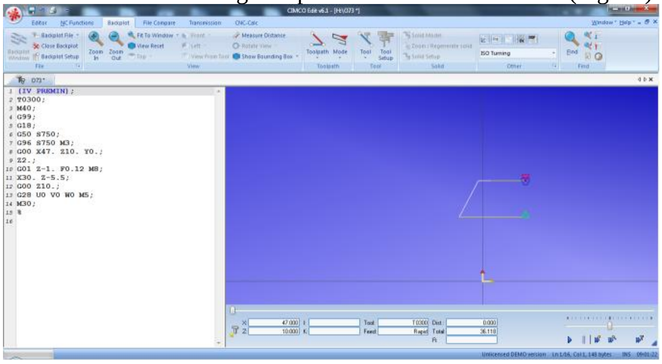

Fig. 9 *Simulation of the third pass*

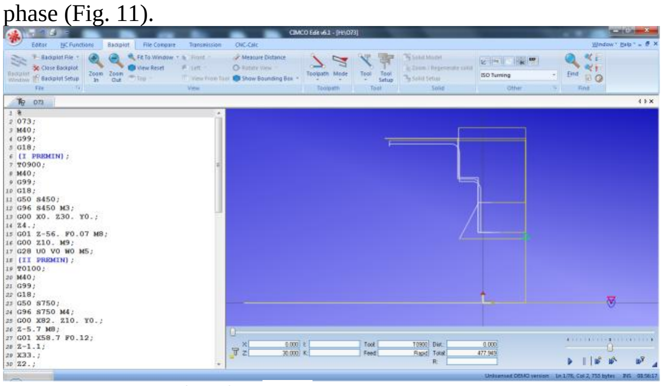
The fourth pass in the first phase is finished with linear movements of the cutting tool pointed in the X and Z axes (Fig. 10).



```
(IV PREMIN);
T0300;
M40;
G99;
G18;
G50 S750;
G96 S750 M3;
G00 X47. Z10. Y0.;
Z2.;
G01 Z-1. F0.12 M8;
X30. Z-5.5;
G00 Z10.;
G28 U0 V0 W0 M5;
M30;
%
```

Fig. 10 *Simulation of the fourth pass*

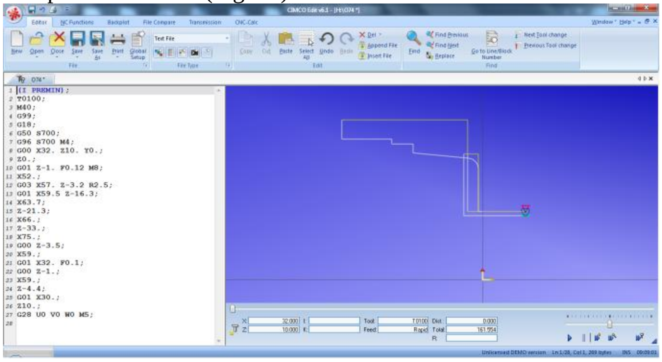
Completing the four passes results in the realization of the first phase (Fig. 11).



```
%
O73;
M40;
G99;
G18;
(I PREMIN);
T0900;
M40;
G99;
G18;
G50 S450;
G96 S450 M3;
G00 X0. Z30. Y0.;
Z4.;
G01 Z-56. F0.07 M8;
G00 Z10. M9;
G28 U0 V0 W0 M5;
(II PREMIN);
T0100;
M40;
G99;
G18;
G50 S750;
G96 S750 M4;
G00 X82. Z10. Y0.;
Z-5.7 M8;
G01 X58.7 F0.12;
Z-1.1;
X33.;
Z2.;
```

Fig. 11 *Simulation of the first phase*

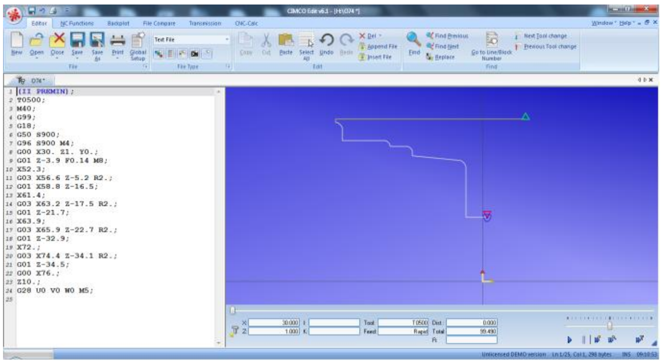
To complete the first pass in the second phase, the cutting tool is moved along the X and Z axes in a linear and circular interpolative motion (Fig. 12).



```
(I PREMIN);
T0100;
M40;
G99;
G18;
G50 S700;
G96 S700 M4;
G00 X32. Z10. Y0.;
Z0.;
G01 Z-1. F0.12 M8;
X52.;
G03 X57. Z-3.2 R2.5;
G01 X59.5 Z-16.3;
X63.7;
Z-21.3;
X66.;
Z-33.;
X75.;
G00 Z-3.5;
X59.;
G01 X32. F0.1;
G00 Z-1.;
X59.;
Z-4.4;
G01 X30.;
Z10.;
G28 U0 V0 W0 M5;
```

Fig. 12 *Simulation of the first pass*

The second pass in the second phase is finished with linear and circular interpolation motions on the cutting tool oriented on the X and Z axes (Fig. 13).



```
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M40;
G99;
G18;
G50 S900;
G96 S900 M4;
G00 X30. Z1. Y0.;
G01 Z-3.9 F0.14 M8;
X52.3;
G03 X56.6 Z-5.2 R2.;
G01 X58.8 Z-16.5;
X61.4;
G03 X63.2 Z-17.5 R2.;
G01 Z-21.7;
X63.9;
G03 X65.9 Z-22.7 R2.;
G01 Z-32.9;
X72.;
G03 X74.4 Z-34.1 R2.;
G01 Z-34.5;
G00 X76.;
Z10.;
G28 U0 V0 W0 M5;
```
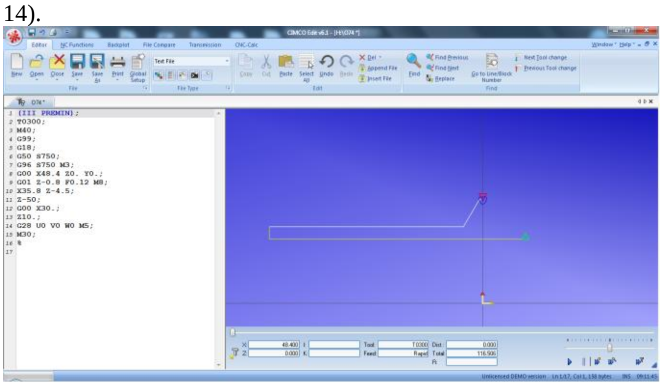

Fig. 13 *Simulation of the second pass*

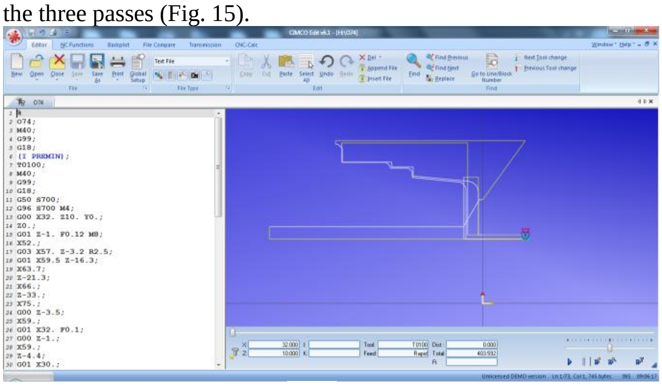
The cutting tool is moved in a linear interpolative motion along the X and Z axes to finish the third pass in the second phase (Fig. 14).



```
(III PREMIN);
T0300;
M40;
G99;
G18;
G50 S750;
G96 S750 M3;
G00 X48.4 Z0. Y0.;
G01 Z-0.8 F0.12 M8;
X35.8 Z-4.5;
Z-50;
G00 X30.;
Z10.;
G28 U0 V0 W0 M5;
M30;
%
```

Fig. 14 *Simulation of the third pass*

The realization of the second phase follows the completion of the three passes (Fig. 15).



```
%
O74;
M40;
G99;
G18;
(I PREMIN);
T0100;
M40;
G99;
G18;
G50 S700;
G96 S700 M4;
G00 X32. Z10. Y0.;
Z0.;
G01 Z-1. F0.12 M8;
X52.;
G03 X57. Z-3.2 R2.5;
G01 X59.5 Z-16.3;
X63.7;
Z-21.3;
X66.;
Z-33.;
X75.;
G00 Z-3.5;
X59.;
G01 X32. F0.1;
G00 Z-1.;
X59.;
Z-4.4;
G01 X30.;
```

Fig. 15 *Simulation of the second phase*

4. Conclusion

In order to develop parts from design to end product with acceptable accuracy, compatibility, machinability, and processability on a CNC machine tool, certain steps must be followed. According to the reliable manufacturing method, the target workpiece is first constructed using particular design software. Then, a specific program of instructions based on G-code is created.

After receiving the program of instructions in the CIMCO Edit v6.1 software program, simulations of the toolpath are generated. Actually, the program of instructions is tested and visualized in the interest of its verification before being applied to the CNC lathe machine tool. Through simulation and verification of the program of instructions, every possible collision is predicted, detected, and eliminated.

The benefit of current and future usage and development of this type of software is that they can rapidly examine various manufacturing strategies without causing any disturbance, damage, or waste. In addition, they are convenient for continuous analysis of the manufacturing processes in order to optimize machining operations, reducing cost and time while raising quality and conserving materials.

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